Compliments of J. S. Diller

DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 38

PERIDOTITE OF ELLIOTT COUNTY, KENTUCKY

WASHINGTON
GOVERNMENT PRINTING OFFICE
1887

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[Bulletin No. 38.]

The publications of the United States Geological Survey are issued in accordance with the statute approved March 3, 1879, which declares that—

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization: And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

"That whenever any document or report shall be ordered printed by Congress, there shall be printed, in addition to the number in each case stated, the 'usual number' (1,900) of copies for binding and distribution among those entitled to receive them."

Except in those cases in which an extra number of any publication has been supplied to the Survey by special resolution of Congress or has been ordered by the Secretary of the Interior, this Office has no copies for gratuitous distribution.

ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880–'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 61 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881–'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882–'83, by J. W. Powell. 1884. 8°. xxxii, 473 pp. 85 pl. and maps.

V. Fifth Annual Report of the United States Geological Survey, 1883–'84, by J. W. Powell. 1885. 8°. xxxvi, 469 pp. 58 pl. and maps.

The Sixth and Seventh Annual Reports are in press.

MONOGRAPHS.

Of the Monographs, Nos. II, III, IV, V, VI, VII, VIII, IX, X, and XI are now published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by Clarence E. Dutton, Capt. U. S. A. 1882. 4°. xiv, 264 pp. 42 pl. and atlas of 24 sheets folio. Price $10.12.

III. Geology of the Comstock Lode and the Washoe District, with atlas, by George F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price $11.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price $1.50.

V. Copper-bearing Rocks of Lake Superior, by Roland D. Irving. 1883. 4°. xvi, 464 pp. 15 l. 29 pl. Price $1.85.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by Wm. M. Fontaine. 1883. 4°. xi, 144 pp. 54 l. 54 pl. Price $1.05.

VII. Silver-Lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. xiii, 200 pp. 16 pl. Price $1.20.

VIII. Paleontology of the Eureka District, by Charles D. Walcott. 1884. 4°. xiii, 298 pp. 24 l. 24 pl. Price $1.10.

IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield. 1885. 4°. xx, 338 pp. 35 pl. Price $1.15.

X. Dinocerata. A Monograph of an Extinct Order of Gigantic Mammals, by Othniel Charles Marsh. 1885. 4°. xviii, 243 pp. 56 l. 56 pl. Price $2.70.

XI. Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada, by Israel Cook Russell. 1885. 4°. xiv, 288 pp. 46 pl. Price $1 75.

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The following is in press, viz:

XII. Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons. 1886. 4°. xxix, 770 pp. 45 pl. and atlas of 35 sheets folio.

The following are in preparation, viz:

I. The Precious Metals, by Clarence King.

— Gasteropoda of the New Jersey Cretaceous and Eocene Marls, by R. P. Whitfield.

— Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague.

— Lake Bonneville, by G. K. Gilbert.

— Sauropoda, by Prof. O. C. Marsh.

— Stegosauria, by Prof. O. C. Marsh.

— Brontotheridæ, by Prof. O. C. Marsh.

— Geology of the Quicksilver Deposits of the Pacific Slope, with atlas, by George F. Becker.

— The Penokee-Gogebic Iron-Bearing Series of North Wisconsin and Michigan, by Roland D. Irving.

— Younger Mesozoic Flora of Virginia, by William M. Fontaine.

— Description of New Fossil Plants from the Dakota Group, by Leo Lesquereux.

— Report on the Denver Coal Basin, by S. F. Emmons.

— Report on Ten-Mile Mining District, Colorado, by S. F. Emmons.

— Report on Silver Cliff Mining District, by S. F. Emmons.

— Flora of the Dakota Group, by J. S. Newberry.

BULLETINS.

The Bulletins of the Survey will contain such papers relating to the general purpose of its work as do not properly come under the heads of Annual Reports or Monographs.

Each of these Bulletins contains but one paper and is complete in itself. They are, however, numbered in a continuous series, and may be united into volumes of convenient size. To facilitate this, each Bulletin has two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1 to 38 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl. Price 10 cents.
2. Gold and Silver Conversion Tables, giving the coining values of troy ounces of fine metal, etc., by Albert Williams, jr. 1883. 8°. 8 pp. Price 5 cents.
3. On the Fossil Faunas of the Upper Devonian, along the meridian of 76° 30′, from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.
4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.
5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.
6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.
7. Mapoteca Geologica Americana. A catalogue of geological maps of America (North and South), 1752–1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price 10 cents.
8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Van Hise. 1884. 8°. 56 pp. 6 pl. Price 10 cents.
9. Report of work done in the Washington Laboratory during the fiscal year 1883–'84. F. W. Clarke, chief chemist; T. M. Chatard, assistant. 1884. 8°. 40 pp. Price 5 cents.
10. On the Cambrian Faunas of North America. Preliminary studies, by Charles D. Walcott. 1884. 8°. 74 pp. 10 pl. Price 5 cents.
11. On the Quaternary and Recent Mollusca of the Great Basin; with Descriptions of New Forms, by R. Ellsworth Call; introduced by a sketch of the Quaternary Lakes of the Great Basin, by G. K. Gilbert. 1884. 8°. 66 pp. 6 pl. Price 5 cents.
12. A Crystallographic Study of the Thinolite of Lake Lahontan, by Edward S. Dana. 1884. 8°. 34 pp. 3 pl. Price 5 cents.
13. Boundaries of the United States and of the several States and Territories, by Henry Gannett, 1885. 8°. 135 pp. Price 10 cents.
14. The Electrical and Magnetic Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1885. 8°. 238 pp. Price 15 cents.
15. On the Mesozoic and Cenozoic Paleontology of California, by Charles A. White. 1885. 8°. 33 pp. Price 5 cents.
16. On the higher Devonian Faunas of Ontario County, New York, by John M. Clarke. 1885. 8°. 86 pp. 3 pl. Price 5 cents.
17. On the Development of Crystallization in the Igneous Rocks of Washoe, Nevada, by Arnold Hague and Joseph P. Iddings. 1885. 8°. 44 pp. Price 5 cents.
18. On Marine Eocene, Fresh-water Miocene, and other Fossil Mollusca of Western North America, by Charles A. White. 1885. 8°. 26 pp. 3 pl. Price 5 cents.
19. Notes on the Stratigraphy of California, by George F. Becker. 1885. 8°. 28 pp. Price 5 cents.
20. Contributions to the Mineralogy of the Rocky Mountains, by Whitman Cross and W. F. Hillebrand. 1885. 8°. 114 pp. 1 pl. Price 10 cents.

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21. The Lignites of the Great Sioux Reservation, by Bailey Willis. 1885. 8°. 16 pp. 5 pl. Price 5 cents.

22. On New Cretaceous Fossils from California, by Charles A. White. 1885. 8°. 25 pp. 5 pl. Price 5 cents.

23. Observations on the Junction between the Eastern Sandstone and the Keweenaw Series on Keweenaw Point, Lake Superior, by R. D. Irving and T. C. Chamberlin. 1885. 8°. 124 pp. 17 pl. Price 15 cents.

24. List of Marine Mollusca, comprising the Quaternary fossils and recent forms from American localities between Cape Hatteras and Cape Roque, including the Bermudas, by William H. Dall. 1885. 8°. 336 pp. Price 25 cents.

25. The Present Technical Condition of the Steel Industry of the United States, by Phineas Barnes. 1885. 8°. 85 pp. Price 10 cents.

26. Copper Smelting, by Henry M. Howe. 1885. 8°. 107 pp. Price 10 cents.

27. Report of work done in the division of Chemistry and Physics, mainly during the fiscal year 1884–'85. 1886. 8°. 80 pp. Price 10 cents.

28. The Gabbros and Associated Hornblende Rocks occurring in the neighborhood of Baltimore, Md., by George H. Williams. 1886. 8°. 78 pp. 4 pl. Price 10 cents.

29. On the Fresh-water Invertebrates of the North American Jurassic, by Charles A. White. 1886. 8°. 41 pp. 4 pl. Price 5 cents.

30. Second contribution to the studies on the Cambrian Faunas of North America, by Charles D. Walcott. 1886. 8°. 369 pp. 33 pl. Price 25 cents.

31. A systematic review of our present knowledge of Fossil Insects, including Myriapods and Arachnids, by Samuel H. Scudder. 1886. 8°. 128 pp. Price 15 cents.

32. Lists and Analyses of the Mineral Springs of the United States; a preliminary study, by Albert C. Peale. 1886. 8°. 235 pp. Price 20 cents.

33. Notes on the Geology of Northern California, by Joseph S. Diller. 1886. 8°. 23 pp. Price 5 cents.

34. On the relation of the Laramie Molluscan Fauna to that of the succeeding Fresh-water Eocene and other groups, by Charles A. White. 1886. 8°. 54 pp. 5 pl. Price 10 cents.

35. The Physical Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1886. 8°. 62 pp. Price 10 cents.

36. Subsidence of fine Solid particles in Liquids, by Carl Barus. 1887. 8°. 58 pp. Price 10 cents.

37. Types of the Laramie Flora, by Lester F. Ward. 1887. 8°. 354 pp. 57 pl. Price 25 cents.

38. Peridotite of Elliott County, Kentucky, by Joseph S. Diller. 1887. 8°. 31 pp. 1 pl. Price 5 cents.

Numbers 1 to 6 of the Bulletins form Volume I; Numbers 7 to 14, Volume II; Numbers 15 to 23, Volume III; Numbers 24 to 30, Volume IV; Numbers 31 to 36, Volume V. Volume VI is not yet complete.

The following are in press, viz:

39. The Upper Beaches and Deltas of the Glacial Lake Agassiz, by Warren Upham.

40. Changes in River Courses in Washington Territory due to Glaciation, by Bailey Willis.

41. Fossil Faunas of the Upper Devonian—the Genesee Section, by Henry S. Williams.

42. Report of work done in the division of Chemistry and Physics, mainly during the fiscal year 1885–'86. F. W. Clarke, chief chemist.

43. On the Tertiary and Cretaceous Strata of the Tuscaloosa, Tombigbee, and Alabama Rivers, by Eugene A. Smith and Lawrence C. Johnson.

In preparation:

44. Historic statement respecting geologic work in Texas, by R. T. Hill.

45. The Nature and Origin of Deposits of Phosphates of Lime, by R. A. F. Penrose, jr.

46. Bibliography of North American Crustacea, by A. W. Vogdes.

— The Gabbros and associated rocks in Delaware, by F. D Chester.

— Report on Louisiana and Texas, by Lawrence C. Johnson.

STATISTICAL PAPERS.

A fourth series of publications, having special reference to the mineral resources of the United States, has been undertaken.

Of that series the following have been published, viz:

Mineral Resources of the United States [1882], by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1883 and 1884, by Albert Williams, jr. 1885. 8°. xiv, 1016 pp. Price 60 cents.

Mineral Resources of the United States, 1885. Division of Mining Statistics and Technology. 1886. 8°. vii, 576 pp. Price 40 cents.

Correspondence relating to the publications of the Survey, and all remittances, which must be by POSTAL NOTE OR MONEY ORDER (not stamps), should be addressed

TO THE DIRECTOR OF THE
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

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UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

PERIDOTITE

OF

ELLIOTT COUNTY, KENTUCKY

BY

Joseph Silas

J. S. DILLER

WASHINGTON

GOVERNMENT PRINTING OFFICE

1887

The Author.

CONTENTS.

ILLUSTRATIONS.

PERIDOTITE OF ELLIOTT COUNTY, KENTUCKY.

BY J. S. DILLER.

INTRODUCTION.

Several years ago Prof. A. R. Crandall, of the Geological Survey of Kentucky, discovered dikes of an interesting eruptive rock between Isom's and Critche's Creeks, near Fielden post office, 6 miles southwest of Willard, in Elliott County, Kentucky. The position of these dikes is shown upon two of the geological maps of Eastern Kentucky. Both maps were prepared under the supervision of John R. Procter, the director of the Kentucky Geological Survey, by Professor Crandall and J. B. Hoeing. One, on a scale of about 4 miles to an inch, is designed to show the relation of the conglomerate uplifts and the dikes; the other, on a scale of 2 miles to an inch, gives the areal distribution of the dikes, the Coal Measures, and the conglomerate in Elliott County. In a vertical section on the same sheet the relations of these terranes are illustrated.

A chemical analysis of the dike rock was made by Messrs. A. M. Peter and J. H. Kastle, in the laboratory of the Geological Survey of Kentucky. Samples of the same material were sent to the United States Geological Survey for microscopic examination. It was found to be a peridotite, and a brief notice of its occurrence was published in Science, January 23, 1885, page 65.

At the request of Mr. Procter and with the approval of Capt. C. E. Dutton and the Director of the United States Geological Survey, I joined Professor Crandall in an excursion to the dikes to collect a complete series of specimens for petrographic investigation.

DISTRIBUTION AND MODE OF OCCURRENCE.

The accompanying map, Plate I, was prepared by enlarging a small portion of the map of Elliott County and introducing the additional data obtained during our late excursion.

At my request, Professor Crandall, who has visited the region a number of times, kindly furnished the following field notes:

This dike represents an eruption of very limited extent laterally, being found only in a small part of the valley of the Little Fork of the Little Sandy River. From its limited range, and also from the readiness with which the rock of which it is composed disintegrates, it does not appear as a noticeable factor in the topography of the

region, and it is with some difficulty that it can be traced beyond the exposures which mark a few points along its surface prolongation. It appears to extend in two diverging lines from Critche's Creek into the valley of Isom's Creek, with several minor offshoots of undetermined but doubtless limited extent, possibly no more than wedge-like projections from the main dike between the strata of the Coal Measures which make up the whole height of the hills of this region. The whole length of the dike in its greatest surface extension appears to be less than a mile, with a width of from a few feet to fifty or more, as indicated by one exposure near Isom's mill, though the slight local disturbance of the including rocks and the inconsiderable metamorphic action, as well as the limited area, indicate no great mass of the intrusive rock. These considerations and some of the conditions noted at Isom's mill suggest the possibility that the exposure there shows a local lateral expansion, rather than the width of the dike. All the rocks of this part of the coal field, including the beds up to coal seven (the Coalton coal of Kentucky, the Sheridan and Nelsonville of Ohio), are cut by both arms of the dike.

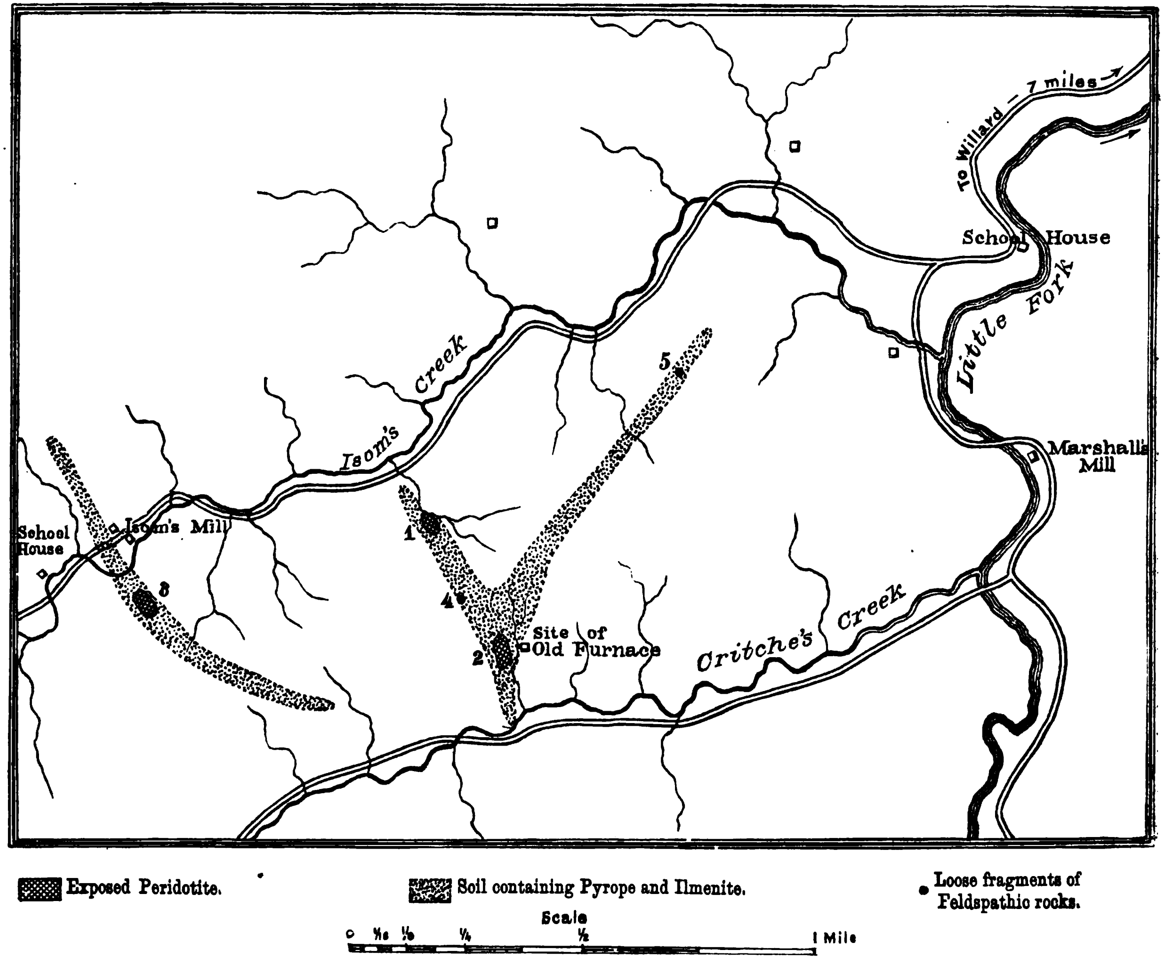
Although there are but three localities where the peridotite is exposed, its areal distribution, as indicated upon the accompanying map (Plate I), can be made out with a high degree of probability by the occurrence of numerous small fragments of ilmenite and pyrope in the soil resulting from its decomposition.

MINERALOGICAL COMPOSITION AND STRUCTURE.

The best and freshest specimens of peridotite were collected at locality marked 1 upon the map, where the specimens were prepared for the educational series. It is a compact, dark greenish rock, with a specific gravity of 2.781. In it are embedded many grains of yellowish olivine, uniformly distributed throughout the mass. Rarely it is fine granular and dense, like many darker colored basalts, but generally the grains of which it is composed are medium sized. Occasionally the olivine grains disappear and the deep green serpentine pervades the whole mass. Besides the olivine and serpentine, which together form nearly 75 per cent. of the rock, there are other minerals which appear in the hand specimen. Most important among these are pyrope and ilmenite, the latter appearing in the form of irregular grains which sometimes attain a diameter of nearly 2 centimeters. A few scales of biotite may be observed. Near the exposed surface the rock becomes yellowish, due to the oxidation of the iron, and softens so that it readily disintegrates. The garnet and much of the ilmenite withstand the atmospheric influences and are found quite fresh and abundant in the sand resulting from the disintegration of the peridotite.

The specimens from localities 1 and 2, the exposures of the eastern dike, are free from included fragments of the rocks through which the peridotite has been extravasated; but those from locality 3, in the western dike near Isom's mill, are full of fragments of shale, which have been greatly indurated and metamorphosed in the operation.

The following table is based directly upon estimates made under the microscope of the areal distribution of the various minerals in the



MAP OF THE PORTION OF ELLIOTT COUNTY IN WHICH THE DIKES OCCUR.

freshest portions of the sections from locality 1, where the peridotite is less altered than at any of the other exposures:

Primary minerals.		Secondary minerals.	
	Per cent.		Per cent.
Olivine	40	Serpentine	30.7
Enstatite	1	Dolomite	14
Biotite	1	Magnetite	2
Pyrope	8	Octahedrite	1.1
Ilmenite	2.2		
Apatite	Trace		

It is not claimed, of course, that this table represents with a high degree of accuracy the mineralogical composition of the rock, yet it closely approximates the real proportions in the sections studied. The table clearly indicates that originally at least 80 per cent. of the rock was olivine and that ultimately it will be nearly all serpentine—or, perhaps, in some places dolomite—with a small proportion of magnetite, ilmenite, garnet, and octahedrite.

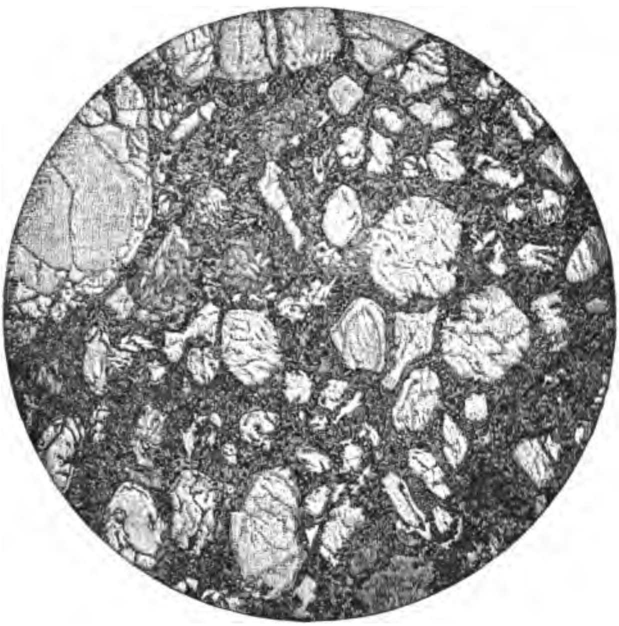


FIG. 1. Section of peridotite seen under the microscope.

The general structure of the rock is illustrated in Fig. 1, which shows the remaining grains of olivine inclosed in a network of serpentine with other products of alteration. The high proportion of olivine in the rock places it among those peridotites which are generally designated dunites, but the presence of some enstatite shows its relationship to another member of the same family.

The olivine grains are generally irregular in form, varying from 0.1 to 1.5 millimeters in diameter, and are penetrated by many fissures. Occasionally, however, they are bounded by sharply defined crystallographic planes, a feature which is unusual for the olivine in peridotites. It occurs in the form, which is common in basaltic lavas, of a short prism terminated by brachydomes without the base, as in Fig. 2. The

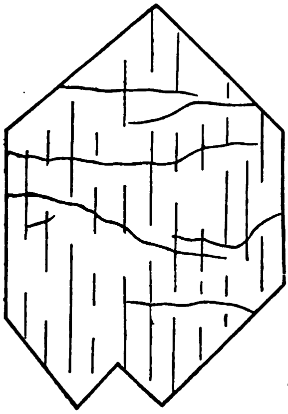


FIG. 2. Crystal of olivine.

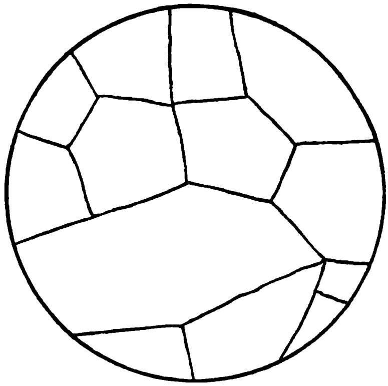


FIG. 3. Original structure of peridotite seen under the microscope.

original structure of the rock is nearly obliterated by recent alteration; but at one point, which is represented in Fig. 3, the manner in which the coarse grains of olivine fit together is plainly discernible. Rarely the aggregating grains are very small, and, although optically distinct, each fits into the irregularities of the other so as to produce a fine granular structure similar to that of the dunite of North Carolina. Under the microscope, especially when the dunite is slightly altered, it holds such a superficial resemblance to a stratified rock that A. A. Julien[1] regarded it as an accumulation of olivine sand derived from an earlier eruptive mass; but Dr. M. E. Wadsworth[2] has shown that in all probability it is eruptive in its present position. The presence of a similar structure in the peridotite of Kentucky, the eruptive origin of which cannot be reasonably questioned, lends strong support to Dr. Wadsworth's conclusions.

The alteration of the olivine to serpentine takes place rapidly in the cross-fractures approximately parallel to the base, but very slowly along the numerous minute fissures in the prism zone. Cleavage parallel to the brachypinacoid is scarcely discernible.

The olivine contains numerous small inclusions, some of which are of a liquid containing a movable bubble. They are arranged in more or less regular planes, often but not always approximately parallel to the

[1] The Dunyte Beds of North Carolina. Proc. Bost. Soc. Nat. Hist., Vol. XXII, p. 141.

[2] Olivine Rocks of North Carolina. Science, Vol. III, p. 486, Apr. 18, 1884.

base. Besides these inclusions, there are other small yellowish-brown or black ones scattered like dust, but rarely so abundant as to interrupt the transparency of the olivine. Occasionally they accumulate in bands across the grains or around their borders, as described by J. W. Judd[1] and others, producing dark cloudings which remain after the olivine has been replaced by serpentine. The olivine was observed to envelop scales of biotite, indicating that the latter belong to an earlier stage of crystallization than the olivine.

In the process of alteration the olivine is transformed into serpentine with the secretion of magnetite. Among the secondary products there is much dolomite, which appears to result from the transformation of the olivine. The abundance of the carbonate present suggests that the olivine might contain a considerable percentage of lime, and to determine this it was prepared for chemical analysis. By means of the Sonstadt solution, with a specific gravity of 2.9, the magnetite, biotite, ilmenite, enstatite, octahedrite, and olivine were separated from the serpentine and other secondary products, With a magnet the magnetite was then removed, and by passing the powder over paper the mica was separated from the other minerals. The mixture of olivine, ilmenite, enstatite, octahedrite, and garnet was then put into the Klein solution and evaporated until crystallization began. At this point the olivine and a trace of enstatite were lifted by the solution and, by decantation, separated from the other minerals. This operation was repeated many times, and finally, picking out all foreign matter under the microscope, the olivine was obtained remarkably pure for chemical analysis. Its specific gravity, determined by using a picnometer, is 3.377. The results of the chemical analysis of the olivine by T. M. Chatard, in the chemical laboratory of the United States Geological Survey, are given in the table of analyses, page 24. It will be noticed that the percentage of lime and alkalies present is unusually large.

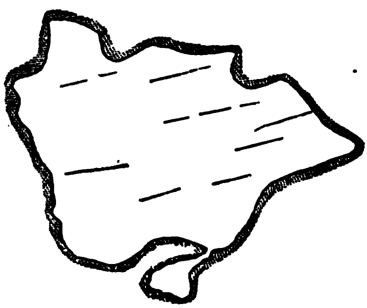


FIG. 4. Corroded enstatite with border.

Pyroxene plays so small a part among the minerals of this rock that it cannot be considered an essential constituent. In the form of irregularly corroded grains, such as is represented in Fig. 4, it is distributed throughout the mass with approximate uniformity, but it constitutes not more than 1 per cent. of the whole. The cleavage is nearly rectangular and the extinction in prismatic sections parallel, indicating with a high degree of probability that the pyroxene is rhombic. It is generally transparent, with a sprinkling of fine dark grains, and is surrounded by a clouded border con-

[1] On the Tertiary and Older Peridotites of Scotland. Quarterly Journal of the Geological Society, August, 1885, p. 354.

forming to the embayed contour. This border is irregular in structure and composition, but is almost always present. Where most prominent it is formed of acicular crystals radiating from the enstatite, but generally it is composed of translucent grains of pyroxene rendered somewhat clouded, apparently by the secretion of ferritic matter. The fibrous mineral is transparent, with strong double refraction and small angle of extinction, indicating that it is hornblende.

The embayments of the irregular enstatite sometimes contain olivine, demonstrating that the pyroxene is an earlier product of crystallization than the olivine and owes its border, at least in part, to the subsequent corrosive action of the magma.

The mica is dark colored, strongly dichroic, with a very small optic axial angle in the plane of the principal ray of the radial figure (Schlagfigur) produced by puncturing a thin plate of the mica with a sharp needle. It doubtless belongs to the biotite series and is sparingly distributed throughout the rock. Figure 5 represents a cross section of a somewhat uncommon scale of brown biotite made up of laminæ differing from one another in pleochroism. The foliæ forming the top and the base of the scale, the shaded portions in Fig. 5, are more deeply colored and strongly dichroic than the light brown portion in the middle. All portions are optically continuous and surrounded by a prominent border composed of colorless mica and oxide of iron. The mica of the border is continuous with the other, and evidently owes its loss of color to leaching out the oxide of iron. With the exception of fine ferritic dust irregularly scattered throughout the scales of mica it is generally free from inclusions. One scale, however, has prominent deep brown isotropic inclusions which lie in the basal plane. They look very like basaltic hornblende in ordinary transmitted light, but the entire absence of double refraction and consequent properties clearly demonstrates that if the substance is crystalline in structure it must belong to the isometric system. It is perhaps significant that the axes of greatest extension in the inclusions are approximately parallel to three sets of sharp fissures which apparently correspond to the rays of the peculiar figure developed by pressure, the so-called Druckfigur. The general appearance of the biotite conveys the impression that it has undergone conditions detrimental to its existence and must belong to the earliest products of crystallization. Of this we have convincing evidence in its relations to other minerals, for biotite is frequently included in olivine. Rarely the biotite is surrounded by an irregular secondary border composed of magnetite and biotite differing widely in pleochroism from the biotite within the border. The biotite of the grain and its border are optically continuous, but, while the pleochroism of the

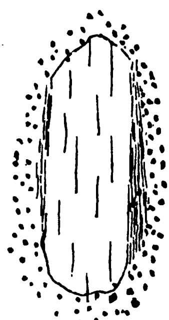


FIG. 5. Biotite.

former ranges from almost colorless to light brownish yellow, that of the latter in corresponding positions is orange-yellow and green.

The relation of the biotite to the garnet is of especial interest and will be noted in discussing the composition of that peculiar envelope in which the pyrope is inclosed. It is evident, however, that the biotite upon the periphery and in the fissures of the garnet is of secondary origin.

Pyrope cannot be considered one of the essential minerals in this rock, yet it is among the most prominent. It occurs in spherical and ellipsoidal grains varying from 1 millimeter to more than a dozen millimeters in diameter. They are found abundantly along the line of the dike in the soil resulting from its disintegration. The small, clear, deep red grains have a specific gravity of 3.673 and are locally regarded as rubies of problematical value, but the paler red, much fractured fragments of larger size have attracted little attention.

The most interesting feature of the pyrope is prominent under the microscope, where it is seen to be surrounded by a border of radial fibers analogous to that described by Fr. Becke[1] and A. Schrauf,[2] and later critically examined by A. v. Lasaulx.[3] The general character of the border is represented in Fig. 6. It is composed of two essentially different substances, both of which are always present, although varying much in proportions. First of these may be mentioned a dark powder, which is frequently so abundant as to render the border opaque. It occurs most abundantly in the outer portion of the border and is chiefly, if not wholly, magnetite; for when carefully detached by a sharp needle from an uncovered section it is found to be strongly magnetic. The second usually inner substance of the ring is of a grayish or reddish brown color and is generally fibrous in structure. Schrauf studied the fibrous substance enveloping the garnets in the serpentine of Kremze, Bohemia, and named it kelyphite. The investigations of Lasaulx have shown that in some cases the border instead of being a single mineral is a mixture of several minerals, chiefly of the pyroxene and amphibole groups. In the example under consideration its composition appears to be exceptional. Although it is commonly made up of closely compacted,

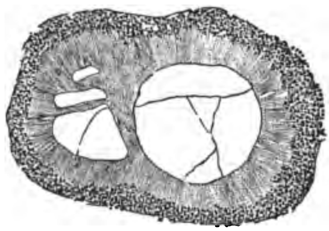


FIG. 6. Pyrope, showing border of biotite and magnetite.

[1] Tschermak's Mittheilungen, iv, 1881, pp. 189, 285.

[2] Beiträge zur Kenntniss des Associations-kreises der Magnesia-Silikate. Zeitschrift für Krystallographie, 1882, VI., pp. 321–388; also Ueber Kelyphite. Neues Jahrbuch, 1884, Bd. II, p. 21.

[3] Ueber Umrindungen von Granat. Sitzungsberichte der niederrhein. Gesellschaft, Bonn, 1882, Juli 3; Verhandlungen des naturhistorischen Vereins der preussischen Rheinlande und Westfalens. Neununddreissigster Jahrgang, zweite Hälfte, Bonn, 1882, p. 114.

very fine, parallel fibers perpendicular to the outer surface of the garnet, it frequently appears as an irregular, non-fibrous fringe upon the inner side of the border, or even completely inclosed within the garnet, where it is usually of a deep brown color. Generally it is distinctly doubly refracting, and when finely fibrous is sometimes strongly colored red and green between crossed nicols. The non-fibrous form of the substance, although deeply colored, is isotropic and consequently not dichroic, but when fibrous the absorption parallel to the fibers is occasionally almost complete. On account of the fineness of the fibers and the density of their aggregation it is not possible to determine the angle of extinction with great precision; nevertheless if the extinction is not parallel the angle is very small indeed. Although many of these borders have been studied about the pyrope in the peridotite from Kentucky, I have not been able to discover convincing evidence of the presence of either pyroxene or hornblende; on the contrary, the evidence clearly indicates that the mineral belongs to the mica group. This conclusion is completely demonstrated by a border, part of which is represented in Fig. 7.

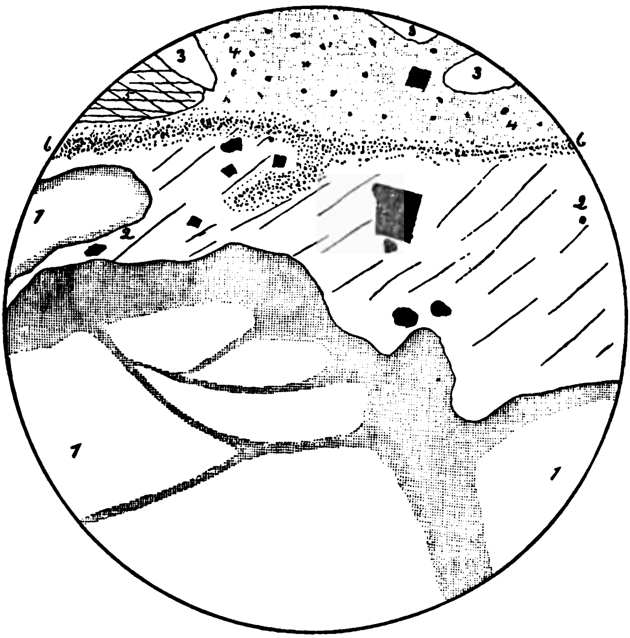


FIG. 7. Part of a border about a grain of pyrope, magnified 80 diameters.

In this case, although the border is not so prominently marked about the whole circumference of the garnet (5 millimeters in diameter) as that represented in Fig. 6, yet there are narrow places along the border where it is distinctly fibrous and grades directly into that represented in Fig. 7 in such a way as to show that both are of the same substance. The uniaxial, negative, strongly dichroic foliated mineral numbered 2

in Fig. 7 is undoubtedly biotite. It extends far into the garnet along fissures and contains besides magnetite small triangular and quadratic sections as well as irregular grains of a yellowish brown isotropic mineral, which in all probability is picotite. The first sight suggests that this deep brown mineral is hornblende, but the absence of all pleochroic phenomena and its regular octahedral form clearly indicate that it cannot belong to the amphibole group. One small pseudomorph after garnet deserves special mention, in that the whole of the middle portion is composed of picotite, which is surrounded by a broad border of magnetite. In the majority of cases, especially where the border is fibrous, the fibers are in direct contact with the clear garnet, but in the section of which Fig. 7 represents a part, where the biotite and picotite are much better developed, the garnet near the border and along fissures is clouded. Besides the biotite and picotite within the compass of the garnet's border, there are traces of calcite and a clear colorless mineral, which, on account of its strong double refraction and the absence of cleavage, is regarded as quartz. It is interesting to note that the quartz almost always occurs in immediate contact with the picotite.

That the shell frequently found about the garnets in peridotitic rocks is composed in most cases essentially of minerals belonging to the pyroxene and amphibole groups has been demonstrated by a number of observers, but as far as I am aware the occurrence of biotite in this connection is here noted for the first time.

It is evident, from the facts represented in Figs. 6 and 7, as already suggested by Lasaulx and Rosenbusch,[1] that the pyrogenic origin of the shell of iron-magnesian silicates frequently enveloping the garnet is generally untenable. The manner in which the enveloping substance is sometimes included in the garnet and penetrates the garnet along fissures clearly demonstrates its secondary origin.

The pyrope, from Kentucky, was carefully analyzed by T. M. Chatard, with the results given in the table of analyses, page 24. It was impracticable to obtain sufficient of the border for chemical examination. The position of the pyrope in the series denoting the order of crystallization is between enstatite, a serpentinous pseudomorph of which it includes, and olivine. Its relation to the primary biotite is not easily determined, from the fact that where the two minerals are found together the biotite is always a secondary product.

Ilmenite is a common and uniformly distributed constituent of the Kentucky peridotite. It is plainly visible in the freshly fractured rock, where it appears in the form of brilliant black grains, varying in size from 1 millimeter to 15 millimeters in diameter. Although subject to considerable alteration it frequently withstands meteoric influ-

[1] H. Rosenbusch: Mikroskopische Physiographie der petrographisch wichtigen Mineralien. Zweite gänzlich umgearbeitete Auflage, 1885, p. 269.

ences with remarkable persistence, appearing abundantly with the garnet in the soil resulting from the disintegration of the peridotite. It is only by means of the ilmenite and pyrope in the soil, as indicated upon the map, that the limits of the dikes can be approximately determined. The ilmenite is readily distinguished from the magnetite, even under the microscope in reflected light, by the brilliant luster of portions of its pitted surface. It has always been observed in large grains and not in the form of fine, spongy particles like magnetite. Under the microscope the ilmenite is frequently seen surrounded, penetrated, and even completely replaced by a mixed group of yellowish and black grains resulting from its alteration. The black opaque grains are magnetite and the yellowish ones probably octahedrite. The specific gravity of the ilmenite is 4.453 and a chemical analysis of it is given in the table, page 24.

Near the southern end of the eastern dike, at a point indicated upon the map, is a prehistoric embankment which appears to have been the foundation for works to smelt the peridotite, probably on account of the supposed value of the bright ilmenite it contains.

Magnetite is abundantly distributed throughout the whole rock. It rarely occurs in the form of well developed octahedrons, but appears generally in irregular, spongy grains a small fraction of a millimeter in diameter. The magnetite results chiefly from the alteration of the olivine and ilmenite, and is therefore rarely, if ever, observed as veritable inclusions in the primary minerals.

The particles picked out of the rock powder by the magnet were treated to an acidulated solution of sulphate of copper in water, and after their removal examination under the microscope showed that many of the grains were coated with copper, indicating that some of the iron was present in the peridotite in a native state.

Abundantly scattered among the other secondary products in the serpentinous network enveloping the remnants of olivine are yellowish clouded grains ranging in size from .004 to .06 millimeters in diameter. The intensity of the yellowish color varies considerably, with a strong inclination towards brown. Its index of refraction is very high, causing it to rise above the neighboring minerals, but its low grade of translucency scarcely more than allows the observer to discover that the mineral is distinctly doubly refracting without determining certainly its degree. The relation of this mineral to the ilmenite clearly indicates that it results from the alteration of the latter and at once suggests that it is a mineral with much titanium, probably titanite or one of the forms of titanic oxide. This is clearly demonstrated by its chemical reactions. With a very sharp steel point a number of these grains were removed from an uncovered section. In the same way a small particle of ilmenite about half replaced by yellow grains adhering to it was isolated. In both cases the material was dissolved in fused $KHSO_4$, and when the product was moistened with a solution of H_2O_2 it turned distinctly yellow, indicating the presence of titanium. The grains are compact and

generally spherical, or at most not more than twice as long as thick. Not infrequently one discovers bounding planes to these grains in the sections that are straight and sharply defined, indicating crystallographic form. Such cases are generally accompanied by a higher degree of transparency and are triangular, square, or diamond shaped. When diamondshaped the grains are most strongly doubly refracting and extinction takes place parallel to the longest diagonal. No trace of cleavage could be discovered, nor could the system of crystallization be determined with certainty, but the facts mentioned render it highly probable that the mineral is octahedrite. The occurrence of octahedrite as an alteration product of ilmenite was observed by the author several years ago in "Schalstein" from Hof in the Fichtelgebirge, Germany.[1] Cohen and Rosenbusch,[2] had previously called attention to the same phenomenon in other localities.

Under the microscope the rock is seen to contain an abundance of carbonate irregularly distributed among the secondary minerals. It is plainly a product of alteration, chiefly of the olivine. It is not affected by warm acetic acid, but effervesces vigorously in ordinary hydrochloric acid. After the calcium has been removed from the solution sodium phosphate yields an abundant crystalline precipitate, showing the presence of magnesia and demonstrating that the carbonate is dolomite. It rarely accumulates in nodules as large as a hazel nut and only at points where the rock is highly altered. The high percentage of lime and carbonic acid present in the peridotite, as shown by chemical analysis No. 4, in the table, page 24, indicates that there is about 14 per cent. of dolomite present and that the carbonate of lime largely predominates in its composition. In some cases, as noted by Dr. M. E. Wadsworth[3] and Prof. R. D. Irving,[4] peridotite is almost completely replaced by dolomite resulting from its alteration.

Next to olivine, serpentine is the most important mineral of the rock, and it occurs in two forms: first in the form of small green scales, which, with dolomite, magnetite, ilmenite, and octahedrite, compose the network in which the remaining olivine is inclosed; frequently, however, the olivine has entirely disappeared, and its place in the meshes is represented by yellowish serpentine, quite unlike the first in its color and inclusions. The first form is bright green of varying intensity, but rarely pleochroic, and it has weak double refraction, yielding between crossed nicols a peculiar bluish aggregate polarization. Its appearance under the microscope is like that of chlorite, but, when isolated and treated with sulphuric acid and cæsium chloride, it did not show the presence of alumina.

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[1] Anatas als Umwandlungsproduct von Titanit in Biotitamphibolgranit der Troas. Neues Jahrbuch, Vol. I, 1883, p. 187.

[2] H. Rosenbusch: Mikroskopische Physiographie der petrographisch wichtigen Mineralien. Band II, p. 336; also, Zweite Auflage, Band I, p. 332.

[3] Lithological studies: Memoirs of the Museum of Comparative Zoölogy, Cambridge, Mass., Vol. XI, Part I, p. 139.

[4] Fifth Annual Report United States Geological Survey, 1883-'84, p. 217.

Strongly contrasted with the green foliated serpentine is the yellowish fibrous form which with dolomite fills the meshes. It is often distinctly fibrous, and sometimes between the fibers are small radial aggregates which show a distinct cross between opposed nicols. The fibers are sometimes distinctly dichroic; the ray oscillating parallel to the longest axis is yellow and perpendicular to it pale greenish, but generally it is not perceptibly dichroic. This form of serpentine, although free from the larger inclusions so common in the other, contains great numbers of small black grains not more than .002 of a millimeter in diameter. These black grains are probably the magnetite secreted in a very fine form in the process of serpentinization, for this serpentine is slightly magnetic.

RELATIONS AND ORIGIN OF THE PERIDOTITE.

The relation of the peridotite to the carboniferous sandstones and shales is of paramount importance in determining its age and origin. Although it has been repeatedly spoken of as a dike the evidence has not yet been fully presented to establish its eruptive character. Concerning the relation of the peridotite to its associated rocks only two hypotheses are worthy of consideration: (1) the peridotite may be older than the carboniferous strata and may have formed on the floor of the sea a peak about which the horizontal strata were deposited; (2) the peridotite may have been erupted through the carboniferous strata. If the first hypothesis is correct we would expect to find the adjacent sandstone composed largely of detritus derived from the peridotite and to exhibit no evidence of contact metamorphism. On the other hand, if the second hypothesis is true, there would not necessarily be a correspondence in the composition of the neighboring rocks, and under favorable conditions the sedimentary deposits would be metamorphosed near their contact with the eruptive.

The rocks of the neighborhood are so disintegrated and covered with soil that notwithstanding our careful search we were unable to discover an exposure of the junction between the two rocks. Nevertheless sufficient evidence has been collected to definitely settle the problem under consideration. Very near an outcrop of the peridotite at locality 1 occurs a calcareous sandstone of which mineralogical and chemical analyses have been made. It is composed of quartz with a smaller proportion of triclinic feldspar, bent scales of muscovite, and biotite, all of which are cemented by carbonate of lime. The quartz grains are distinctly subangular and not infrequently contain minute needles of rutile. The sandstone is conspicuously unlike the adjacent peridotite in its composition and clearly indicates that the peridotite was not in its present position at the time the sandstone was deposited. This difference is further emphasized by the chemical analysis, No. 7, page 24. When it is compared with the analysis of the peridotite (No. 4) from the same locality the dissimilarity is so prominent as to dispel at once the thought that they may be genetically connected.

This discordance in the composition of the two rocks stimulated the

hope of discovering evidence of contact metamorphism, and in this we were not disappointed, for at locality 3 hardened shale was found near the peridotite under such circumstances that its induration is certainly attributable to the influence of the eruptive mass. The effects produced by the peridotite upon the adjacent sedimentary rocks may be considered first and subsequently those experienced by the peridotite itself near the contact. For convenience the shale may be regarded as made up of two classes of constituents, (1) the grains of sand and (2) the matrix or cement in which they are embedded. Among about a dozen specimens of the shale examined the relative proportions of the sand grains and cement vary greatly. In one case the former predominates, so that the rock may be regarded as a fine-grained sandstone, but generally the earthy cement is in excess and frequently forms almost the whole mass. Some of the clear grains are quartz, but most of them are of orthoclase, microcline, or plagioclase feldspar. The matrix varies greatly, consisting chiefly where least altered of a heterogeneous clayey substance containing a multitude of microlites,[1] numerous small scales of mica, and particles of black organic pigment with a trace of magnetite.

The metamorphic influence of the peridotite is clearly traceable in the distribution of the pigment and the development of a crystalline structure in the cement. The latter becomes more and more micaceous in character as the metamorphism increases, and the parallel arrangement of the foliæ renders the rock more easily split, sometimes even fissile in one direction. The distribution of the pigment is generally uniform throughout the mass, but in a portion of one of the sections it is clearly aggregated into groups, giving the section a mottled appearance, and approaches in character the so-called Knotenthonschiefer so admirably investigated by Rosenbusch.[2] The name spilosite has been used to designate such rocks in the contact zone about basic eruptive masses. The dark spots (Knoten) are not visible in the hand specimens, but may be plainly seen in the section and appear to be completely isotropic. The lighter colored areas among these show between crossed nicols doubly refracting grains, which are chiefly mica associated with feldspar. Chemical analysis No. 9 was made of a fragment of indurated shale in which the microscopic spots were most distinctly observed. Analysis No. 10 is of a fragment of shale included in the peridotite. The size and abundance of the mica scales in the altered shale is in a general way proportional to the intensity of the metamorphic influence. A person is frequently surprised, however, to find small fragments of shale, less than a centimeter in diameter, completely enveloped by the peridotite and yet not extremely metamorphosed. In many cases the small fragments are almost completely altered to micaceous minerals,

[1] These microlites correspond exactly to those so frequently observed in clay-slate and in a number of cases have been demonstrated to be rutile. H. Rosenbusch: Mikroskopische Physiographie der petrographisch wichtigen Mineralien. Zweite Auflage, p. 304.

[2] Die Steiger Schiefer und ihre Contactzone an dem Granititen von Barr-Andlau und Hohwald.

which appear to be of several sorts. A portion is completely colorless and when examined in converging light between crossed nicols is found to be distinctly biaxial, but the hyperbolæ when farthest apart do not quite reach the outer limit of the field of vision. It is strongly doubly refracting, with the peculiar sheen commonly observed in muscovite. The other mica is more or less distinctly colored, being greenish or yellowish bordering upon brown, and is distinctly dichroic light to dark yellowish green. It occurs in irregular scales and fibers, with strong double refraction, and appears to be nearly or altogether uniaxial. The colorless mica is frequently continuous with that which contains considerable coloring matter, and I have frequently been in doubt as to the presence of more than one kind of mica.

The included fragments of shale are always surrounded by a border of colorless mica whose scales are intricately intermingled. Frequently, although not generally, the foliæ have their greatest dimension at right angles to the surface of the inclusion. This border varies in width, but is usually about 3 millimeters in thickness and composed almost exclusively of well developed irregular scales of colorless mica. The same mineral is distributed quite abundantly in the enveloped fragment. It appears also sparingly scattered for a short distance away upon the outside of the border among the serpentine and other alteration products of the peridotite. The brownish colored mica, which is so common in the altered shale adjacent to the peridotite, appears very different in the included fragments, where a higher degree of alteration has taken place. It here appears to be a gray, clouded, translucent mass, which, between crossed nicols, is seen to be made up of scales of mica. This advanced stage of metamorphism in the included fragments is accompanied by the appearance of very interesting bodies which have not been definitely determined. They are pale yellowish in color, translucent to almost transparent, and perfectly isotropic. The diameter of these little balls is generally about .02 of a millimeter and they are remarkably uniform in size and shape. In general appearance they closely resemble the small translucent grains of octahedrite in the adjacent peridotite, but they cannot be octahedrite, for they are soluble in hydrochloric acid. When a flake of mica containing them is heated to a bright red heat they become less translucent and somewhat more earthy in appearance, but the change is not prominent. In the small fragments the globules are usually numerous, scattered throughout the scales of clouded mica, but most abundant and less regular in form near the border of the inclusion, where they sometimes produce a quite distinct band just inside the one of colorless mica. In the fragments where this peculiar isotropic substance is most abundant there is but little well developed mica. Traces of other unimportant minerals occur under such circumstances as to render their determination a matter of great difficulty. Rarely among the scales of clear mica in the border which always surrounds included fragments of shale, may be observed elongated particles of a deep brown mineral, which in ordinary trans-

mitted light resembles hornblende, but is not pleochroic, has weak double refraction and an extinction angle of about 37 degrees. The recent discovery that the Kimberley and other diamond mines of South Africa are upon volcanic necks of peridotite penetrating carbonaceous shale[1] attaches much interest to the peridotite of Kentucky, where similar geologic relations exist. Diamonds have not yet been discovered in Kentucky. The shale in the immediate vicinity of the dikes does not appear to be sufficiently rich in carbonaceous matter to excite much enthusiasm.[2]

An endomorphic effect experienced by the peridotite near its contact with the sedimentary rocks is apparently discernible in a structure which may be regarded as variolitic in character. The peridotite at this point contains many fragments of included shale, but in the hand specimens one sees nothing resembling a variolite. In a few of the thin sections, however, here and there among the olivine and its alteration products may be observed light brown, translucent, homogeneous, compact bodies similar in general appearance to the isolated sphærolites which sometimes occur in fresh andesitic rocks. Lighter colored veinlets run through them and between crossed nicols they are seen to be radially fibrous and show a distinct but not sharply defined black cross. The quadrants are rather intensely but not brilliantly red, yellow, or green, with a peculiar fuzzy appearance. These varioles are seen only in sections containing inclusions of shale and appear to be most abundant in their neighborhood; but, on the other hand, small included fragments of shale are frequently observed without any such structure near them.

The facts which indicate the relation of the peridotite to the adjacent carboniferous strata may be briefly recapitulated. In mineralogical and chemical composition the two rocks are very unlike. The carboniferous shales near their junction with the peridotite are greatly indurated by the development of a crystalline structure, which as it augments obliterates the sedimentary character and gives rise to a schistose arrangement of the particles. Fragments of shale of various sizes are included in the peridotite and have been greatly metamorphosed. On the other hand, the peridotite near its junction with the sedimentary rocks, owing to their influence upon it, has locally developed a variolitic structure such as has been not infrequently observed in diabases and other eruptive rocks near their contact with older formations. These facts demonstrate beyond a doubt that the peridotite is a truly eruptive rock which has been forced up through the carboniferous strata. Peridotites are common rocks, but they are almost always associated with others of a highly crystalline character in regions of great disturbance, and their origin cannot be clearly demonstrated. By many authors they are regarded as eruptive, but by others they are considered to belong to sedimentary formations. In one of the very

[1] H. Carvill Lewis: The Genesis of the Diamond, Science, Vol. VIII, p. 345.

[2] The Genesis of the Diamond, Science, Vol. VIII, p. 392, October 29, 1886.

latest works on lithology[1] they are included among "katogene" rocks, i. e., rocks which, like sandstone, are formed of material deposited at a level lower than its source. In this country the dunite associated with the corundum deposits of North Carolina has been regarded by Dr. A. A. Julien,[2] who studied the rocks both in the field and under the microscope, as a deposit of olivine sand derived from an earlier eruptive mass. Dr. M. E. Wadsworth,[3] after a critical examination, considered them to be eruptive, and my investigations of the same rocks convince me that Dr. Wadsworth's conclusion is correct. The dunite of North Carolina and the one in Elliott County, Kentucky, are essentially the same in structure and composition, and I believe are also of the same eruptive origin. Certain it is that the one in Kentucky is eruptive, and all the essential phenomena in North Carolina point in the same direction. It is important to note, however, a marked difference in the character of the alteration in the two cases. In the dunite of North Carolina, as well as in a number of undescribed peridotites of Northern California and elsewhere,[4] which like it are found associated with highly contorted and metamorphosed strata, the olivine frequently alters to hornblende. In Kentucky, however, where regional metamorphism is entirely absent, no such alteration has been observed.

CHEMICAL COMPOSITION.

The following table presents in a concise form all of the chemical analyses which have been made of the peridotite, its constituents, and associated rocks:

Chemical analyses of peridotite and associated rocks.

	(1) Olivine.	(2) Pyrope.	(3) Ilmenite.	(4) Peridotite.	(5) Peridotite.	(6) Granite.	(7) Calcareous sandstone near peridotite.	(8) Fine grained fissile sandstone near dike.	(9) Indurated shale near dike.	(10) Fragment of shale included in peridotite.
Water at 110° (H_2O)	0.14	0.17	0.20	8.92	10.90	0.51	0.85	1.94	....	1.40
Water at red heat (H_2O)	0.66	....	....	....	....	....	2.32	5.17	8.78	9.00
Carbonic acid (CO_2)	....	....	....	6.60	5.65	....	6.20	.....	0.55	0.88
Silicic acid (SiO_2)	40.05	41.32	0.76	29.81	29.43	60.56	60.78	60.25	41.32	35.53
Titanic acid (TiO_2)	0.07	0.16	49.32	2.20	1.48	1.19	0.03	0.23	0.48	0.95
Phosphoric acid (P_2O_5)	0.04	None	Trace	0.35	Trace	0.30	0.09	0.10	0.08	0.08
Chromic oxide (Cr_2O_3)	0.24	0.91	0.74	0.43	0.14	....	....	....	Trace	......
Alumina (Al_2O_3)	0.39	21.21	2.84	2.01	2.36	16.19	10.54	20.18	20.71	18.23
Ferric oxide (Fe_2O_3)	2.36	4.21	9.13	5.16	....	5.19	3.27	1.53	2.59	2.46
Ferrous oxide (FeO)	7.14	7.93	27.81	4.35	9.06	2.41	....	3.42	5.46	4.81

[1] E. Kalkowsky: Elemente der Lithologie, p. 236.

[2] Proceedings Boston Society Natural History, Vol. XXII, p. 141.

[3] Science, Vol. III, p. 286, April 18, 1884.

[4] Mikroskopische Physiographie der petrographisch wichtigen Mineralien. Zweite gänzlich umgearbeitete Auflage, pp. 412, 413.

Chemical analyses of peridotite and associated rocks—Continued.

	(1) Olivine.	(2) Pyrope.	(3) Ilmenite.	(4) Peridotite.	(5) Peridotite.	(6) Granite.	(7) Calcareous sandstone near peridotite.	(8) Fine grained fissile sandstone near dike.	(9) Indurated shale near dike.	(10) Fragment of shale included in peridotite.
Manganous oxide (MnO)	0.20	0.34	0.20	0.23	....	0.36	0.10	0.10	0.17	30.1
Nickelous oxide (NiO)	(CoO) Trace	......	....	0.05	0.60	......	......	......	....	......
Lime (CaO)	1.16	4.94	0.23	7.69	6.94	2.09	10.15	0.51	9.91	21.17
Magnesia (MgO)	46.68	19.32	8.68	32.41	31.66	1.30	1.59	3.52	1.91	2.01
Potash (K_2O)	0.21	......	....	0.20	0.65	4.82	2.36	3.17	0.88	1.08
Soda (Na_2O)	0.08	0.07	0.19	0.11	0.78	4.78	1.41	0.39	7.19	2.53
Sulphur (S)	......	......	....	None	*0.20	......	......	......	....	......
Sulphuric acid (SO_3)	......	......	....	0.28	0.30	......	......	......	....	......
Total	99.42	100.58	100.10	100.86	100.15	99.70	99.78	100.51	100.03	100.26
Specific gravity	3.377	3.673	4.453	2.781	2.697	2.633	......	......	....	2.489

*In sulphides.

Analysis No. 5 of the peridotite was made by A. M. Peter and J. H. Kastle in the chemical laboratory of the Geological Survey of Kentucky. All the other analyses were made by T. M. Chatard in the chemical laboratory of the United States Geological Survey.

Although the freshest samples of the peridotite were selected for analysis, the large percentage of water and carbonic acid present indicates a high degree of alteration. As compared with the analyses of other typical peridotites the amount of silica appears very low, but this does not necessarily indicate that any of the silica has been removed, for its apparent decrease is due, at least in large part, to the addition of water and carbonic acid from external sources.

LOOSE FRAGMENTS OF FELDSPATHIC ROCKS FOUND WITH THE PERIDOTITE.

At the localities marked 4 and 5 upon the map loose fragments of highly feldspathic rocks occur upon the surface, mixed with the soil containing garnets and ilmenite. The fragments found at the two places, although somewhat dissimilar, are holocrystalline and granitic in structure, altogether unlike the adjacent sandstones and shales, and it is evident that they belong to the eruptive mass. They deserve special attention and will be noticed separately, beginning with those found upon the hillside at locality 4, a short distance northwest of the site of the old furnace. Several fragments were found at this place, scattered along the border of the dike for a distance of 50 yards. The hand specimen looks very like a rotten syenite and is easily crumbled be-

tween the fingers. Notwithstanding the fact of its feeble cohesion the feldspar, which is by far the most prominent mineral of the rock, exhibits numerous bright cleavage and crystal faces. Dark colored minerals are not conspicuous. Among these, ilmenite may be easily recognized by its jet black color and brilliant luster. Under the microscope the rock is seen to be composed chiefly of feldspar. Considerable quartz and ilmenite are present, with a trace of hornblende, sphene, and apatite. The feldspar is of two sorts, orthoclase and plagioclase, readily distinguished by their optical characters. They are generally grown together as perthite and may be completely irregular in their interlockings, but frequently the parallel sheets of each, varying from .005 to .01 millimeter in thickness, join in the plane of the orthopinacoid and are quite regular in outline. The orthoclase is somewhat clouded by kaolinization, but the plagioclase is colorless and transparent, with bright polarization between crossed nicols. The polysynthetic twinning which characterizes the plagioclase is generally parallel to the clinopinacoid, but frequently associated with these lamellæ are others parallel to the orthopinacoid. Cleavage lamellæ of the plagioclase parallel to the base have a very small angle (2 degrees) of extinction. This fact indicates that the plagioclase is not pure albite, but has a considerable admixture of the anorthite molecule and is probably oligoclase. This conclusion is substantiated by a test with hydrofluorsilicic acid, which shows the presence of both calcium and sodium. The feldspar, especially the perthitic form, contains numerous inclusions. Besides apatite and ilmenite, the earlier products of crystallization, the feldspar contains numerous acicular groups of light brown scales, whose character could not be definitely determined. The scales are frequently hexagonal in form, and although all are in a row their hexagonal planes may make any angle with the longer axis of the group. These acicular groups generally lie at an angle of about 45 or 90 degrees to the plane of the perthitic lamellæ.

Quartz occurs in clear, colorless grains, the uniaxial positive character of which can be easily demonstrated. It contains occasional liquid and gas inclusions, but none of the kind so common in the feldspar. Quartz and feldspar are each included in the other and must have crystallized synchronously. The green dichroic mineral regarded as hornblende does not appear with well defined crystallographic features. It has rather strong double refraction, but the angle of extinction could not be sharply determined in the absence of well defined cleavage. Chemical analysis No. 6 in the table is of this feldspathic rock. Its mineralogical and chemical constitution indicates that it belongs rather to the granites than to the syenites, although it is closely related to the latter group.

The other specimen of feldspathic rock collected near the eastern end of the dike at locality 5 is quite unlike the one just described. The only fragment found in this case is very solid and fresh in appearance and

somewhat gneissoid in structure. In the hand specimen it appears to be composed chiefly of feldspar and garnet and a smaller proportion of a greenish mineral, but in addition to these the microscope reveals the presence of small quantities of quartz, enstatite, apatite, and other accessory minerals. In structure it is holocrystalline and distinctly granular. None of its constituents, excepting the minute acicular inclusions, has a well defined crystallographic outline. The feldspar is plagioclase with a much larger angle of extinction and broader twinning lamellæ than the oligoclase of the other fragment. Orthoclase, if present at all, is rare and does not appear in perthitic growth with plagioclase. Occasionally the feldspar is bent or broken, as if subjected to great strain since its crystallization. Nearly or quite a third of the rock is formed of garnet, which to the unaided eye looks very like the pyrope of the peridotite. It differs from the latter, however, very prominently under the microscope in containing numerous included microlites. These minute acicular crystals are of a yellowish mineral like rutile, but between crossed nicols are seen to be brilliantly doubly refracting with inclined extinction. The angle of extinction varies from 0 degree to 30 degrees, indicating that the mineral crystallizes in the monoclinic system. Cross sections of the small crystals have a rhombic or elliptical outline. Rarely these inclusions are arranged irregularly, but generally they appear to be nearly equally distributed in three sets. The longer axes of the crystals in each set are parallel, but the longer axes of the different sets make an angle of about 45 degrees with one another. Frequently these minute crystals are associated with cavities, as represented in the annexed figure 8.

The first example looks as though the crystal had been formed by partly filling a cavity, of which *a* represents the portion remaining unoccupied. In the second example, however, the cavity *e* is between *b* and *c*, which are optically parallel, indicating that they are parts of the same crystal and that the cavity has been formed by dissolving away its middle portion. Although these inclusions are numerous in the garnet they are even more abundant in the green mineral, which has not been definitely determined. It has almost as high an index of refraction as garnet and is strongly doubly refracting. It is plainly biaxial, with extinction inclined to the indistinct cleavage. The quartz, enstatite, apatite, and a yellowish brown mineral like rutile present nothing worthy of special mention. The structure and mineralogical composition of this rock fragment closely ally it to the granulites.

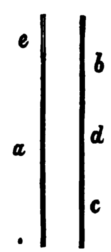

FIG. 8. Included microlites and cavities in garnet.

The presence of the two kinds of fragments of feldspathic rocks intermingled with the soil resulting from the disintegration of the peridotite may be explained in many ways, but from the fact that the dike occurs in nearly horizontal, unaltered, stratified rocks, many scores of miles

away from the nearest known outcrops of similar massive terranes, it is highly probable that the fragments are indigenous to the region and were brought to the surface by an eruption. Their striking dissimilarity in composition to the peridotite indicates that they cannot with any considerable degree of probability be regarded as early products of crystallization in the peridotitic magma, but must be looked upon rather as inclusions of the country rock brought up from beneath a vast thickness of unaltered Paleozoic strata. The presence of a number of granitic fragments, nearly in line along the border of the olivine rock, suggests that the granite may have reached the surface by an independent eruption instead of as an inclusion brought up from the depths by the peridotite.

AGE OF THE PERIDOTITE.

Professor Crandall has kindly furnished me the following field notes upon the general geological features of Eastern Kentucky, which have an important bearing upon the age of the peridotite:

The dike is found near the line which marks the eastern limit of the Silurian anticlinal of Ohio and Kentucky, as modified by the final uplift of the Carboniferous series. That the Silurian axis was involved somewhat in this movement is indicated by the conditions as now observed; but there remains a clearly defined anticlinal ridge, with the border of the Coal Measures on its eastward slope, as has been pointed out in various reports on the geology of Eastern Kentucky. The eastward dip is interrupted along a line which is, in a general way, parallel to the border of the coal field. This interruption is more or less prominent as marked by a reduced dip, or by horizontal beds, or even by a reverse dip of the exposed strata. The last condition is more noticeable in Elliott County than elsewhere. The line of change falls but a few miles east of the dike. The reverse and the varying dips eastward and southeast from this line are the result of the upheaval of the Cumberland coal field, a movement which hinged on the Silurian axis along this line. The Silurian axis still remains, a prominent, unmistakable feature, as remarked, but reduced in width eastward and somewhat obscured in the topography as modified by the resulting drainage. That there may have been profound fractures of the rock formations along this line of hinge movement follows as a matter of course. The Elliott County dike may be supposed to add something to the probability of such fractures as the result of this movement. The movement as described may, in turn, throw some light on the occurrence of this outlying dike.

Transverse to the axis of uplift are some minor wave-like undulations, especially southward, and involving Elliott County in part, as noticed in Lesley's report on the outcrop line of the eastern coal field of Kentucky. These undulations have a determinative relation to the drainage, as in the case of the Licking, the Red, and the Kentucky Rivers, and it is not improbable that they may have an important relation to the faults which traverse adjacent parts of the Silurian axis and terminate in the border of the coal field. The most striking modification of the general dip by transverse flexure is found along a belt which extends from the Big Sandy River, south of Louisa, in Lawrence County, to a point opposite to and but a few miles east of the dike. The dip along this belt is to the northward from a ridge of conglomerate rock, which elsewhere falls below the drainage along the border of the coal fields. It is along this slope that the oil and gas developments of Lawrence and Martin Counties are being made. The prominent geological basin centering at Willard is formed by a junction of this northward dip with the general southeast dip, increased by local depression. Willard is about 6 miles in a direct line northeast of the dike.

The dike is found near the juncture of two lines of flexure: one parallel with the axis of uplift of the Coal Measures and the other a transverse or secondary undulation of considerable local prominence. Whether or not these conditions throw light on the occurrence of igneous rock far from any region of great disturbance, they form an interesting, if not a necessary, background to any general view of the dike and its surroundings.

That the eruption of the peridotite occurred since the deposition of the Carboniferous strata with which it is associated is a matter that does not admit of question, but whether or not its extrusion took place at the close of the Carboniferous period synchronously with the plication of the Paleozoic strata of the Appalachian system is difficult to determine.

The very slight disturbance suffered by the strata through which the peridotite reached the surface suggests that its extrusion may not have been connected with the great orographic movements at the close of the Carboniferous age, but rather with the subsequent dislocations, like that of Pine Mountain in Southeastern Kentucky, which, according to Professor Shaler, occurred at a much later date.

SUMMARY.

The rock recently discovered by the State Geological Survey in Elliott County, Kentucky, is a peridotite, which on account of the great predominance of olivine in its composition is closely related to dunite, such as occurs in the corundum region of North Carolina.

Among the interesting features of the peridotite is the occurrence of some of the olivine in well defined crystals. It contains a considerable proportion of pyrope and ilmenite; the former, as in many other peridotites, is surrounded by a fibrous border composed chiefly of biotite.

The peridotite is associated with nearly horizontal Carboniferous sandstones and shales, from which it differs widely in chemical and mineralogical constitution. It not only includes numerous fragments, but has greatly indurated the shale near the contact and has itself suffered endomorphic effects in the production of a sphærolitic structure corresponding to that of variolites. These facts clearly indicate that the peridotite is eruptive and render its occurrence of much importance, for it so rarely happens that peridotites are found under such circumstances that their eruptive character can be fully established.

WASHINGTON, D. C., *April* 26, 1886.

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NOTICE.

The bulletins of the United States Geological Survey are numbered in a continuous series and will be bound in volumes of convenient size.

This bulletin will be included in Volume VI.